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Procedia Engineering 84 (2014) 812 – 817

**Procedia
Engineering**www.elsevier.com/locate/procedia

“2014 ISSST”, 2014 International Symposium on Safety Science and Technology

A study of soft rock roadway coupling support in Xiajing Coal Mine

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Abstract

Highly stressed soft rock subject to expansion deformation is particularly difficult to control. Field observations and experiments analysis show that an exhaust air roadway, level 100 of the Xiajing Coal Mine in Guangxi, China, is located in an intumescent rock with high in situ stress. Then we designed a bolt-mesh-anchor coupling support for the roadway repair and reinforcement, which consists of a first coupling support with bolt-mesh and secondary reinforcement with anchor cables. Field monitoring results show that bolt-mesh -cable coupling support has guaranteed the stabilization of the roadway and reduced the deformation of the surrounding rock considerably.

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Peer-review under responsibility of scientific committee of Beijing Institute of Technology

Keywords: soft rock; highly stress; deformation mechanism; coupling support; bolt-mesh-anchor support

1. Introduction

As the depth of underground mining increasing, failure problems in the soft rock get more serious. Roadways surrounded by soft rock at great depth show the typical deformation characteristics of high stress, large deformations, and support difficulties[1-3].

Conventional supports cannot effectively control deformation and failure and this has brought great difficulties to coal mine safety[4,5]. Much research work has been conducted on the mechanical characteristics of the surrounding rock and stability control techniques of mining tunnels at great depth. Concepts of “changing axis theory”, “combined support technology”, “anchor-arc board support measures”, “excavation damaged zone”, “primary and secondary loading zones”, as well as other supporting theories and techniques were proposed[2,6-8].

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It was found that a bolt-mesh-anchor support technique could effectively control deformation of tunnels at great depth[9]. But if the coupling effect between this bolt-mesh-anchor support and deformation of the surrounding rock was not realized, deformations of the bolt-mesh support and tensile failure of the anchors will appear.

Therefore, the key issue of a successful bolt-mesh-anchor support is to harmonize deformations between support and rock mass[10]. Research on roadway deformation and the coupling support in deep, soft rock is particularly important. This has a profound significance to achieve sustainable economic and efficient coal mine development.

In this paper a return air roadway in the Xiajing Coal Mine located in deep soft rock at level 100 is discussed. A bolt-mesh-anchor coupling support as the main truss supporting technology is studied.

2. Geological characteristics of Xiajing Coal Mine

2.1. Lithology

Xiajing Coal Mine level 100 (at a buried depth of 600 m) return air roadway is located in the Devonian and Carboniferous strata and has a lithology consisting of sandstone, quartz sandstone, mudstone, and a sandstones interbedded with mudstone. A geologic histogram of the roadway is shown in Fig. 1.

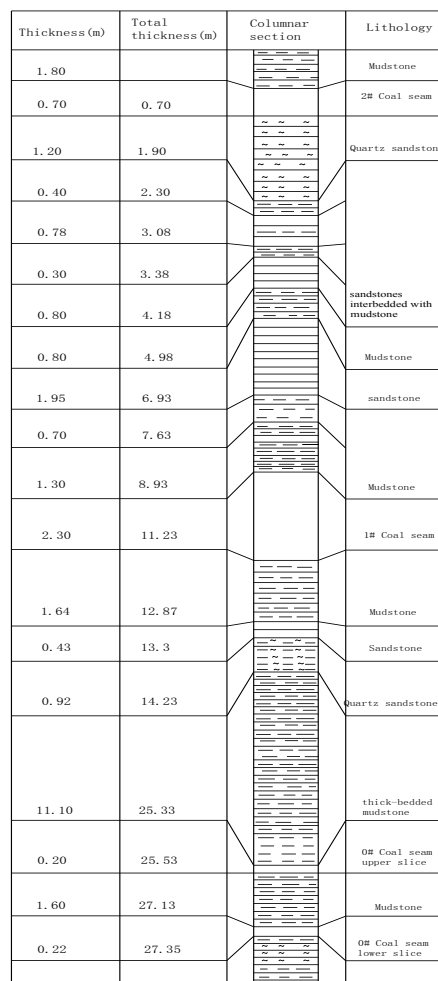


Fig. 1. Geologic histogram of the roadway.

2.2. Lithologic analysis

Samples were taken from the air roadway at level 100, level 150 and level 200, the total amount is 28 specimens. They were analyzed with electron microscopy and X-ray diffraction, the results being shown here in Table 1.

The material contains clay minerals that swell. The clay minerals are mainly illite, kaolinite, and amorphous clay. This has a great impact on the rock strength. The swelling propensity upon water absorption of these minerals is considerable and the clay minerals has a relative content of 40%. In the mixed layers it is more than 60–65%. The rock surrounding roadway is a soft rock that swells.

Table 1. X-ray diffraction results: mineral type and content (%).

	Amorphous clay	illite	kaolinite	gypsum	Quartz	Pyrite	Calcite	ankerite	siderite	total
mean	3.82	12.23	23.36	1.06	51.68	2.27	1.03	2.99	1.58	100.0

2.3. Mechanical properties of rock analysis

28 specimens of rock and coal were taken at level 100, level 150 and level 200. They were tested with rock mechanics testing machine and rock point load instrument system, the results being shown here in Table 2.

Table 2. Mechanical properties of rock.

No	sample	Density (t/m ³)	Compressive strength (MPa)	Tensile strength (MPa)	Elasticity (GPa)	Poisson's ratio	Bonding strength (MPa)	Friction angle(°)
1	sand stone (1)	2.63	98.7	15.1	46.19	0.29	5.8	69.3
2	sand stone (2)	2.64	97.4	12.7	54.02	0.29	7.3	69.0
3	quartz sandstone	2.66	182	13.2	56.67	0.29	7.3	70.1
4	mudstone (1)	2.46	31.3	1.2	—	—	8.9	31
5	mudstone (2)	2.64	28.6	1.1	—	—	8.1	31
6	coal	1.35	9.6	0.4	—	—	3.1	24

2.4. Stress field analysis

Xiajing Coal Mine is located in the south-west margin of Jiangnan antecline, eastern edge of Bai Dan anticline. The main geological structure is monoclinic, strata inclines in an easterly direction with angle of 15°. In the southern area of the mine there are a group of fold belt from north- east to south-west.

Stress in the rock is influenced by these geological structures. In-situ stress measurement results suggest that the maximum stress in this region is a horizontal stress. Based on measured values, the linear regression equation between the maximum horizontal principal stress or vertical stress and depth of the measuring point was generated, as follow.

$$\sigma_{hmax} = 0.0298H + 5.165$$

$$\sigma_v = 0.0291H - 0.7611$$

where σ_{hmax} is the maximum horizontal principal stress, σ_v is the vertical principal stress, H is the depth of the measuring point.

The maximum principal stress is 20–21 MPa at an azimuth of 206°.

3. An analysis of the deformation mechanism

At the start of the roadway excavation, an ordinary bolt-mesh support was applied. The deformation of the surrounding rock mass was large and accidents of roof falls occurred frequently.

Some damage photos are given below. As shown in Fig. 2, it is clear that: the roof of the roadway has suffered extensive damage and localized failure was particularly serious. The wall of the roadway was damaged seriously. The wall of the roadway is in a special geological formation where the expansion of soft rock by tectonic stress and water erosion has occurred. The lower strength of these materials allows the coal wall to undergo a great amount of drum deformation. Shrinkage of the roadway cross section is generally 30% and can sometimes reach 60% in Xiajing Coal Mine, which seriously affects safety during production.

Spot observations show that the deformation mechanism in the 100 level roadway consists of more than one type and includes mechanical deformation as well as expansion of the highly stressed composite soft rock.



Fig. 2. Damage of the roadway under early forms of support.

4. Coupling support design test

4.1. Principles of coupling support

The deformation of the air roadway required the use of a bolt-mesh-anchor coupling support technique for roadway repair and reinforcement. It consists of a first coupling support with bolt-mesh and secondary reinforcement with anchor cables, which are introduced timely at key positions[2, 11].

A bolt-mesh-anchor coupling support is meant to harmonize deformations by the coupling among bolt-mesh-anchor support and the coupling between support and rock mass[12]. This way, rock strength may be improved by the retaining structures and by coupling between components of them. The roadway is stabilized by a self-supporting anchor network involving soft layer coupled support trusses, bottom bolting, and lag anchor bracing. Bolt-mesh-tray coupling trusses enhance the strength of the surrounding rock mass. Lag pre-stressed grouting anchors provide a suspension for stabilizing the tunnel. The bottom bolting controls floor heave in the roadway by cutting off lateral slip-lines. Overall stability is achieved by homogenizing the loads through integrated support design.

4.2. Support materials and timbering parameters

The timbering parameters of lane were determined according to timbering engineering empirical formula.

(1) Anchors bolts: Bolts is made in left – handed thread steel, with a total length of 2400 mm and $\Phi 22$ mm in diameter. It is anchored at the ends with two pieces of Z2350 resins .Preloading force in each bolt is more than

80kN. Compound steel tray is 100mm×100mm×10mm in size. The distance between rows is 800×800 mm in a three flower arrangement.

(2) Anchor cables: Cables 21.6 mm in diameter and 7400 mm long with an exposed length less than 300 mm are used. It is anchored at the ends with three pieces of Z2350 resins, the pre-stressing force of cable is 98kN. Compound steel tray is 300mm×300mm×10mm in size. The distance between rows is 1600×1600 mm in a 2×3 layout, the interval between cables is 800-1200 mm.

(3) Metal netting: A 4.5 mm diameter steel welded mesh 3200×1000 mm in size with a mesh pitch 100×100 mm is used in the roof of roadway, and 2500×1000 mm in the wall .

(4) W - shaped steel strip: Type BHW-250-3-3000-3 steel strip is used in the roof of roadway, Type BHW-250-3-2300-3 in the wall.

(5) Corner anchors: Seamless tubing $\Phi 32$ mm in diameter are used with steel bars and grouting at a row distance of 800 mm.

(6) Concrete: The spray thickness of the initially applied concrete is 40 mm. The results showed that the rock was stable toward deformation and the steel frame was re-sprayed. One to two months after installing the permanent bracing a spray layer was applied to cover the frame and to provide an outer protective layer 60 mm thick. This layer consisted of C20 grade concrete.

(7) Bottom arches: Poured concrete was placed 150 mm thick. The permanent design formed a high floor from pouring concrete of a C20 grade.

The design is shown in Fig. 3.

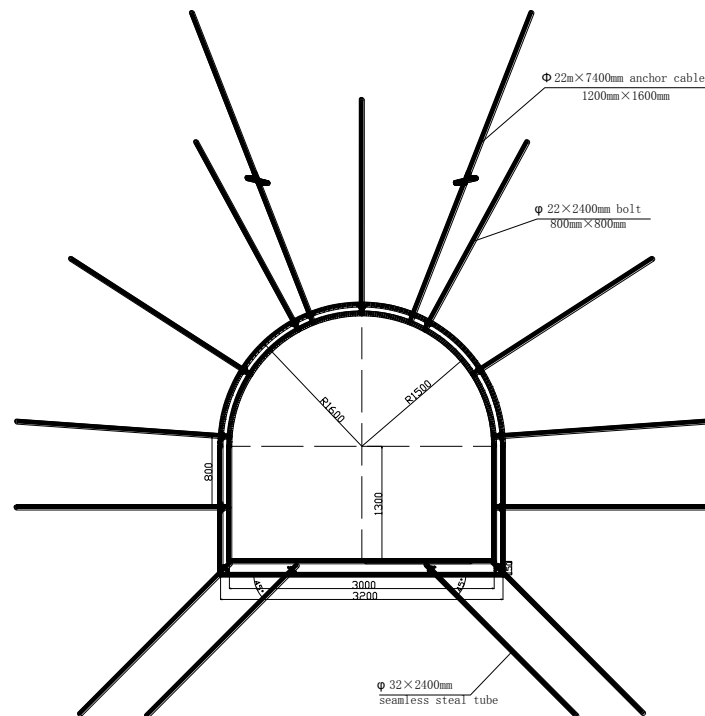


Fig. 3. Design of a bolt-mesh-anchor coupling support.

4.3. Discussion of test results

After using the scheme of bolt-mesh-anchor coupling support, the field monitoring shows that the contraction of the two sidewalls, the roof subsidence, and the floor heave were efficiently controlled. Within three months

monitoring period, the minimum roof subsidence speed was no more than 0.2 mm/d and averaging 1.12 mm/d. The maximum relative convergence of the side walls was 80 mm. The maximum loading of every anchor rod run up to 40-49 KN in two sidewalls, the minimum loading is 20-24 KN.

5. Conclusions

The deformation characteristics of surrounding rock of broken and soft roadway are complicated and related to lithology, physical - mechanical properties of rock and field stress etc. A field investigation and experiments analysis were used to determine the cause of damage to the roadway. A bolt-mesh-anchor coupling support was designed, which used bolt-mesh, spray, anchor cables and corner coupled truss supports, and implemented for the repair and reinforcement of the return air roadway in level 100.

The field monitoring shows that the designed coupling support had efficiently controlled the deformation of the surrounding rock in this soft seam. This design can be used for similar roadways support.

Acknowledgments

This study is supported by the Natural Science Foundation of Guangxi (No 2011GXNSFA018020).

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